National Aeronautics and Space Administration

Studies of Stratopause Evolution Using Satellite Data and Meteorological Analyses: Stratospheric Sudden Warmings and Interannual/Interhemispheric Variability

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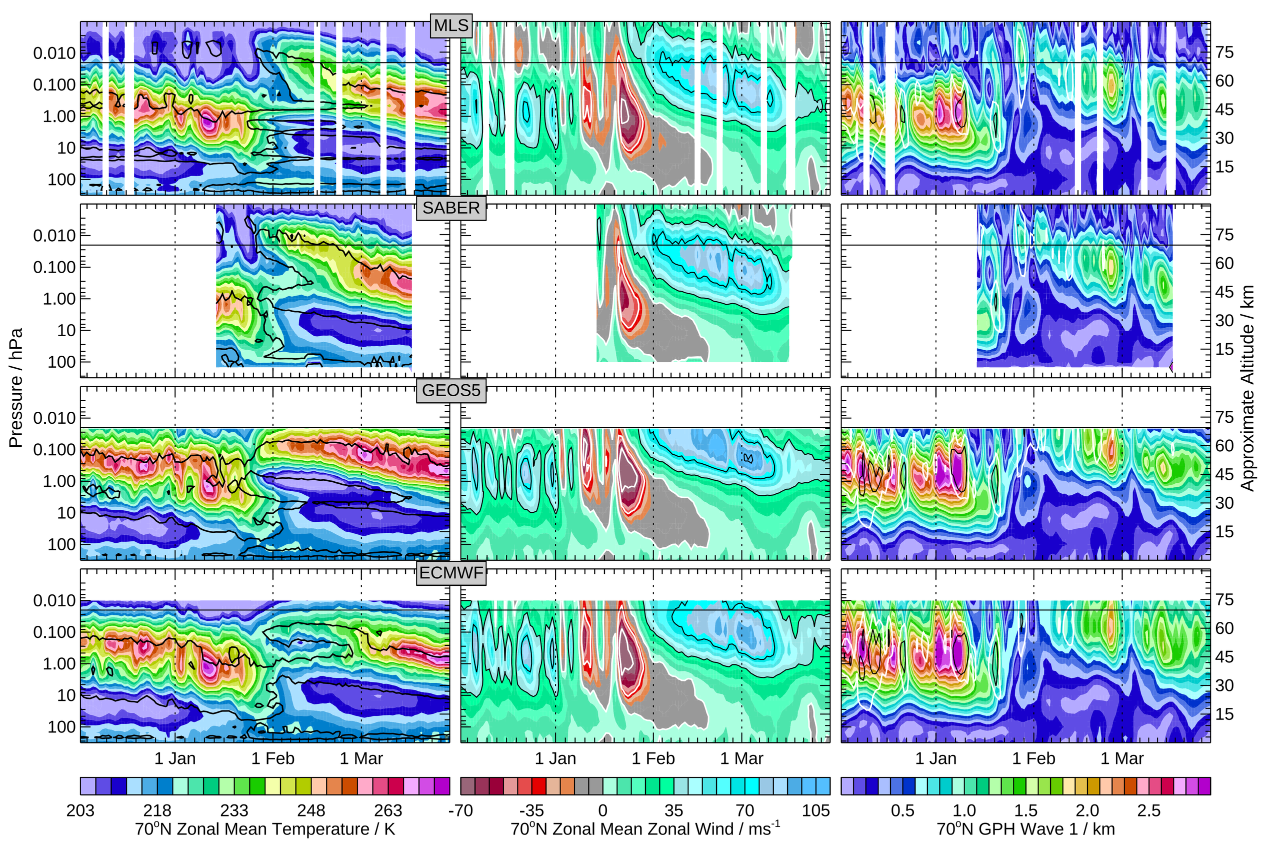
Introduction

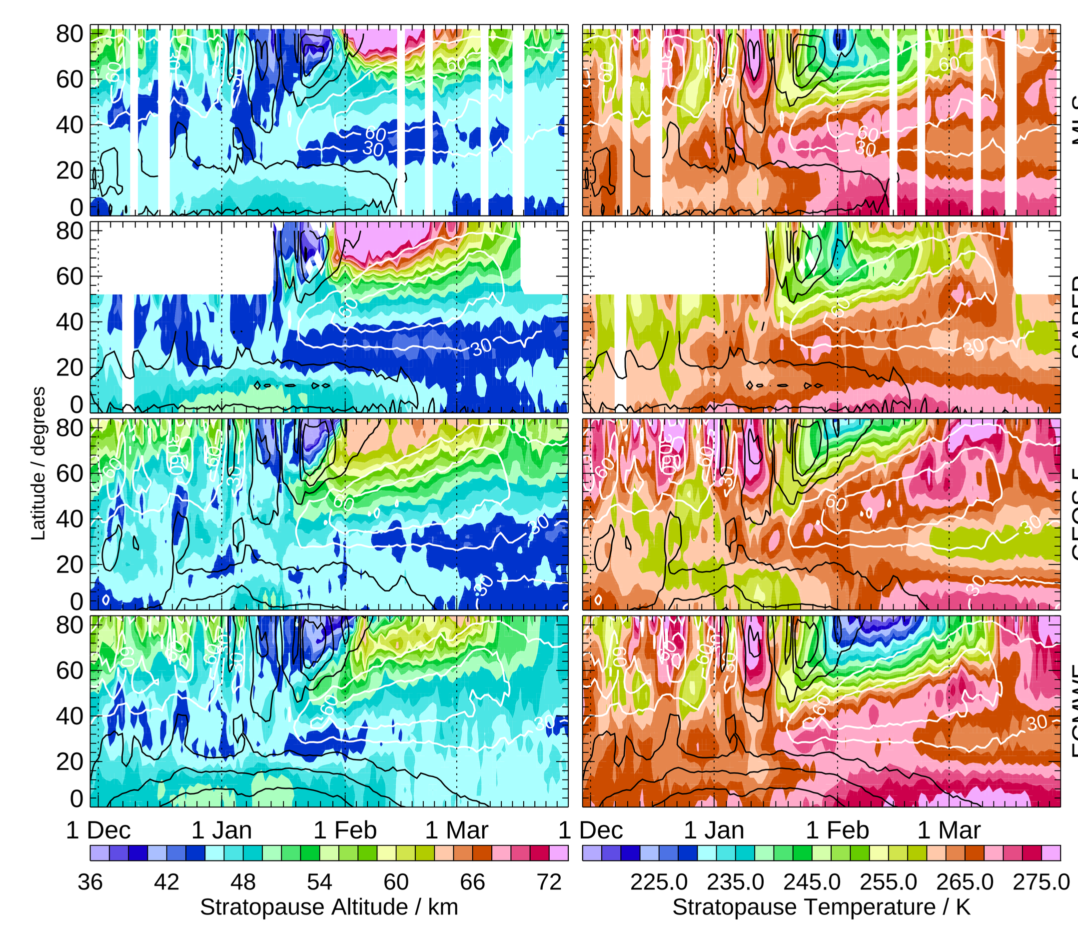
Until the past several years, daily global or hemispheric temperature datasets extending through the mesosphere were largely unavailable. With the launch of the Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) instrument in 2002 and the Aura Microwave Limb Sounder (MLS) in 2004, we now have a wealth of such data. Some data centers, particularly the European Center for Medium-Range Weather Forecasting (ECMWF) and NASA's Global Modelling and Assimilation Office (GMAO) are providing operational assimilated meteorological analyses extending into the mesosphere. Above the upper stratosphere, there are no direct data constraints, so the fields depend strongly on the dynamics and parametrizations in the underlying general circulation models, and there have heretofore been few data with which to compare them. MLS and SABER data have been used to detail the evolution of the stratopause during recent polar winters, and to assess the skill of the analyses in capturing the observed behavior. We show examples for the 2006 major stratospheric sudden warming (SSW), as well as results examining interannual and interhemispheric variability of stratopause evolution and its representation in data assimilation systems. Improvements in representation of the stratopause in recent research assimilations are shown.

1 Stratopause Evolution During the 2006 Stratospheric Major Warming [Manney et al, 2008, JGR, 113, D11115, doi:10.1029/2007JD009097]

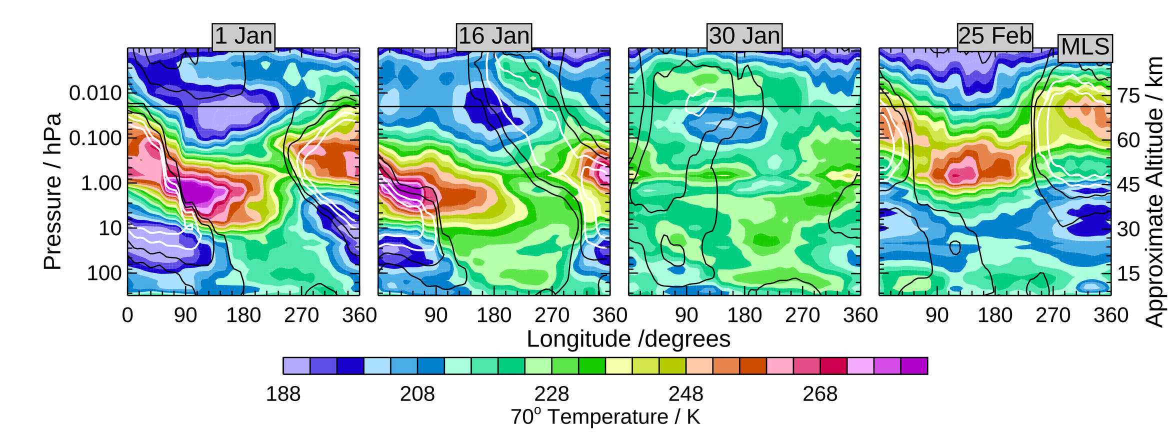


- Figure above shows 70°N zonal mean temperature (left, black lines static stability $4\times10^{-4}\ s^{-2}$), zonal mean wind, and planetary wave 1 amplitudes (white and black lines wave 2 amplitudes) during the 2005-2006 NH winter from MLS and SABER satellite data, and from GEOS-5 and ECMWF assimilated analyses
- Figure to right shows zonal mean stratopause altitude and temperature from the same datasets

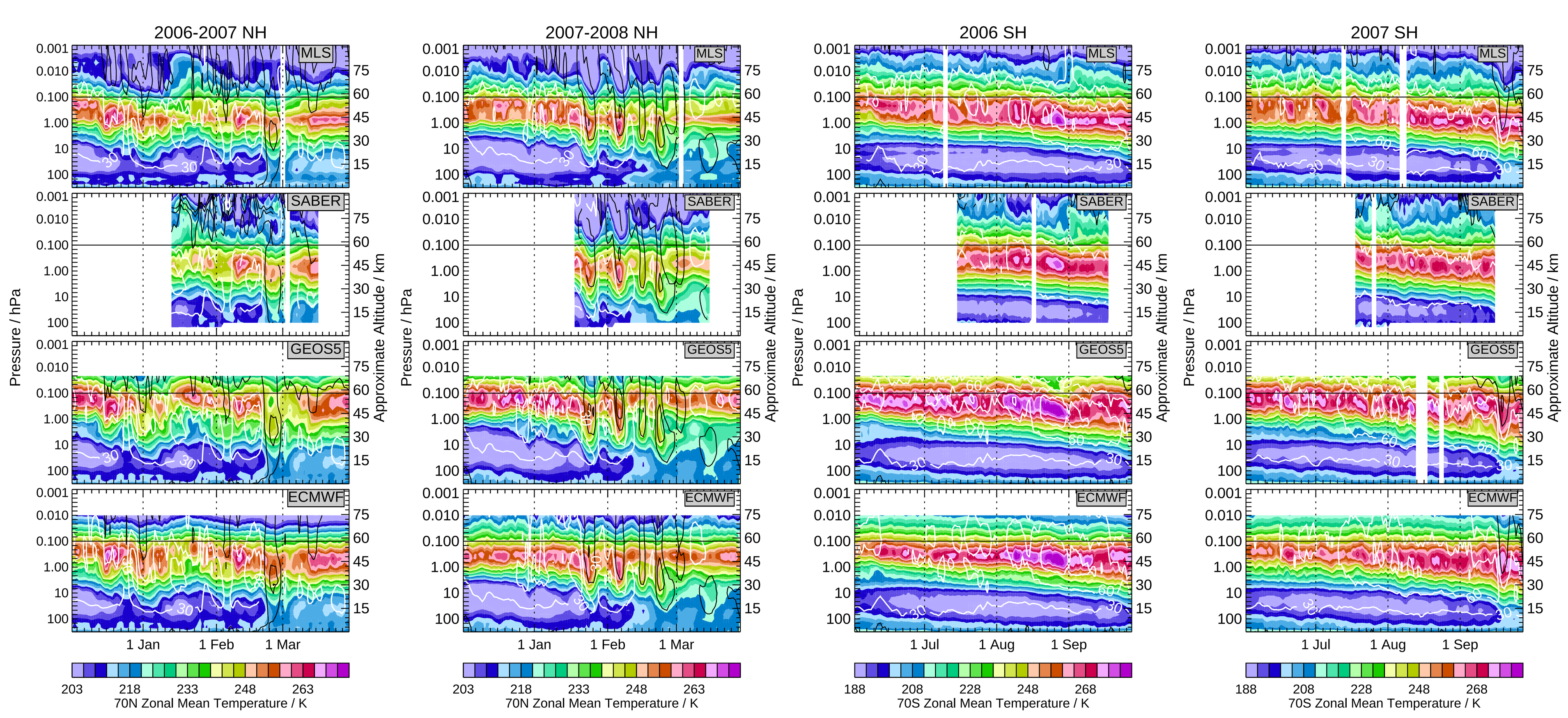
- The stratopause dropped ∼20-30 km during the prolonged 2006 SSW, followed by a complete breakdown of the warm stratopause layer and reformation at very high altitude, near 75 km
- Planetary waves amplified in the mesosphere as the stratopause reformed, and descended in parallel with stratopause descent and warming



- While the two satellite datasets agree well, the GEOS-5 and ECMWF analyses:
  - Fail to capture the stratopause reformation at high altitude that occurs near or above their model tops
  - Misrepresent the nearly isothermal region after the vortex breakdown and underestimate stratopause altitude variations during and after the SSW
  - Have winds and planetary wave amplitudes that are too strong in the region surrounding the stratopause
  - Because of the deficiencies in the analyses' temperatures, their radiative heating rates are badly biased: GEOS-5 overestimates and ECMWF underestimates radiative cooling in the lower mesosphere
- The Figure below shows cross-sections around 70°N of MLS temperatures (black and white lines show increasingly negative geopotential eddy, so polar vortex is inside white lines)
- The secondary temperature maximum that extends westward (and equatorward, not shown) from the separated polar stratopause is a feature that has not previously been documented

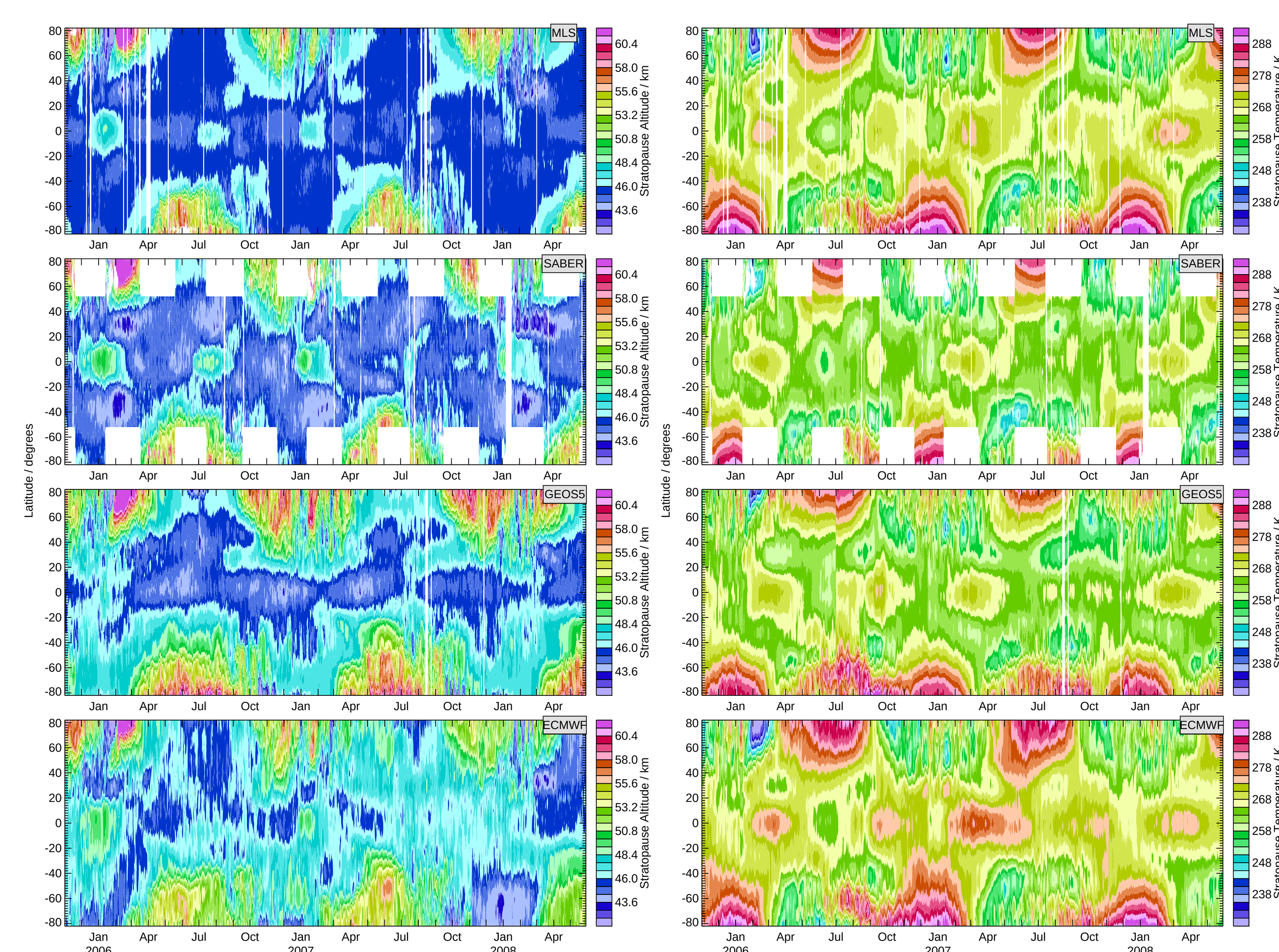


2 Interannual and Interhemispheric Variability



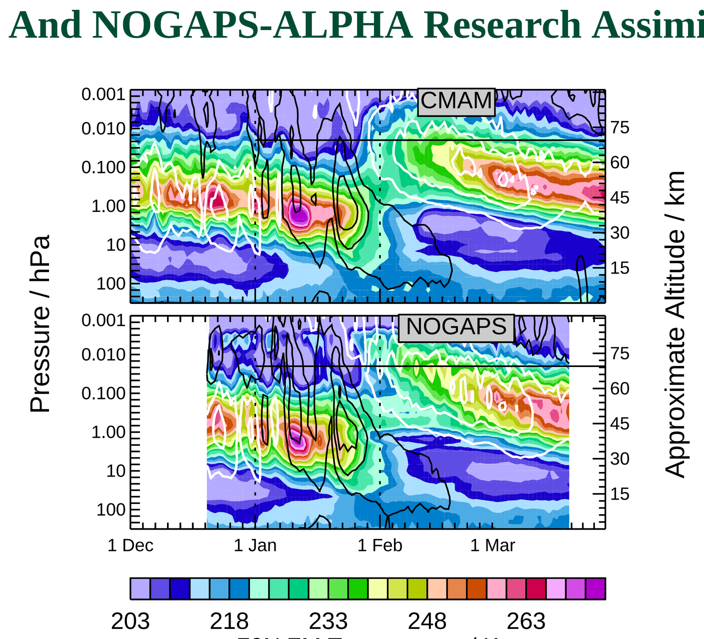
- The panels above show zonal mean temperatures (with westerly wind contours overlaid in white and easterlies in black) at 70°N during the 2006-2007 and 2007-2008 NH winters, and at 70°S during the 2006 and 2007 SH winters (note different color ranges in NH and SH plots) from MLS, SABER, GEOS-5 and ECMWF
- The stratopause moves generally downward over the winter
- Stratopause evolution is much more monotonic in the colder, more quiescent SH winter, but still shows significant interannual variability
- A hint of a double stratopause is apparent in MLS and SABER in January 2006 in the NH, and at the beginning of Sep 2006 in the SH
- Brief major SSWs occurred in the NH in late February 2007 and 2008 (when black easterly zonal wind contours extend below 10 hPa); several strong minor SSWs preceded the 2008 major warming (black contours dipping below 1 hPa)
- Unlike the prolonged SSW in 2006, the 2007 and 2008 SSWs resulted in only modest changes in stratopause altitude and temperature
- Persistent biases are still apparent in GEOS-5 and ECMWF in less disturbed conditions:
  - The GEOS-5 stratopause is typically too high and too warm in both hemispheres (but GEOS-5 does get a hint of the double stratopause in September 2006)
  - The ECMWF stratopause altitude is slightly low and cool in the NH, but close to MLS and SABER in the SH

- The figures below show global zonal mean stratopause altitude and temperature from Nov 2005 through May 2008 from MLS, SABER, GEOS-5 and ECMWF

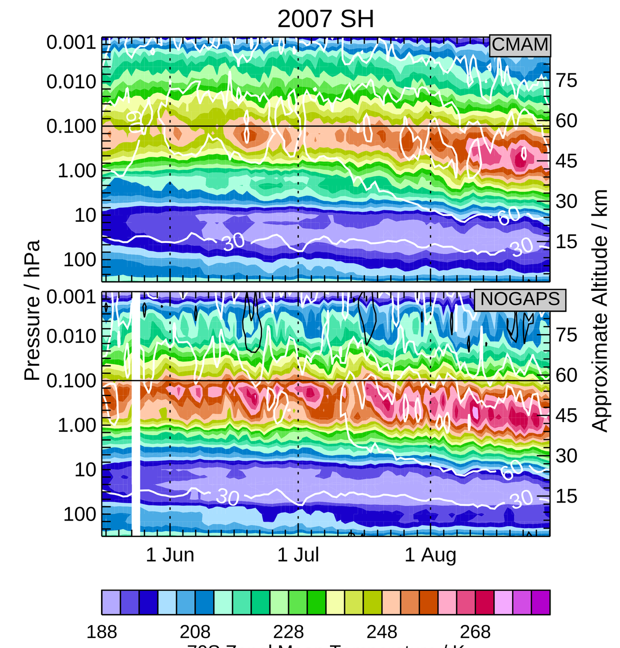


- The polar stratopause is generally high and cold during winter, well-separated in altitude from the midlatitude stratopause
- Stratopause altitudes increase only slightly between the equator and the summer pole
- MLS and SABER stratopause altitudes and temperatures show a clear semi-annual variation in the equatorial regions
- In the SH mid to late winter (July, August), MLS data show warming and lowering of the stratopause, which is reflected in ECMWF fields, with warming strongly overestimated in GEOS-5 fields
- GEOS-5 and ECMWF both show serious deficiencies in capturing the overall equatorial and mid-latitude stratopause evolution

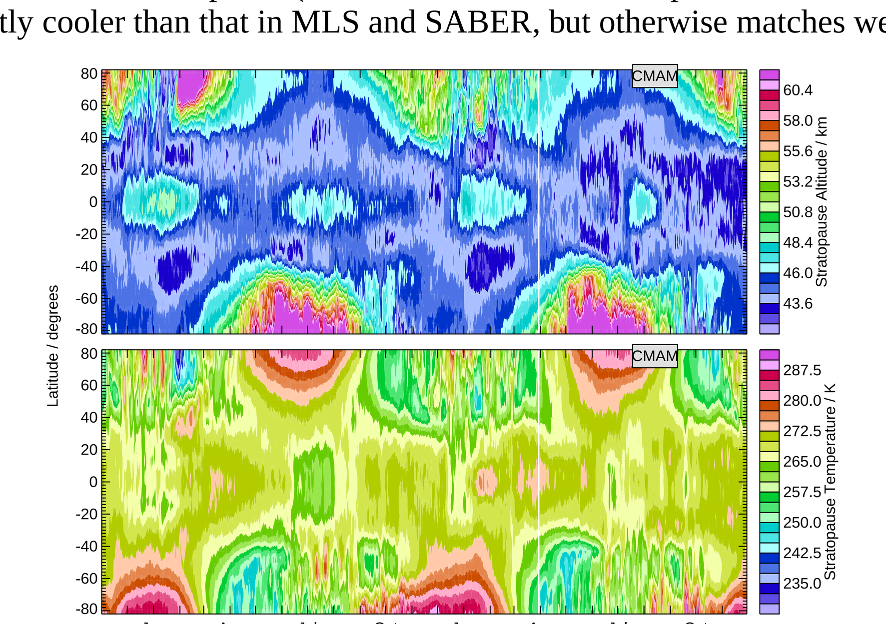
3 CMAM And NOGAPS-ALPHA Research Assimilations



- The figure above shows analyses from the Canadian Middle Atmosphere Model (CMAM) data assimilation system (top) and the Naval Research Laboratory's NOGAPS-ALPHA data assimilation system during the 2006 SSW
- The CMAM has a very high model top and a sophisticated non-orographic gravity-wave drag parametrization
- The NOGAPS-ALPHA run assimilated MLS and SABER temperatures [e.g., Eckermann et al, JASTP, submitted] up to 0.002 hPa
- Both approaches result in considerable improvement in stratopause structure and evolution after the SSW, with altitude and temperature of the reformed stratopause much closer to MLS and SABER than in the operational analyses



- CMAM and NOGAPS-ALPHA runs during the 2007 SH winter also show some improvement in stratopause representation
- The CMAM stratopause is slightly high, and is colder than that in MLS and SABER
- The NOGAPS stratopause (with MLS and SABER temperatures assimilated) is slightly cooler than that in MLS and SABER, but otherwise matches well



- A long CMAM run being done for IPY shows substantial improvements in global stratopause structure over that seen in GEOS-5 and ECMWF
- The semi-annual variation seen in MLS and SABER data is captured
- The SH polar stratopause is slightly higher and cooler than that in MLS and SABER data in both summer and winter

4 Continuing Work

- Interannual and interhemispheric variability studies using satellite data (initially Aura MLS and SABER) are being extended to develop a climatology of global stratopause evolution
- These studies will include analysis of data from ACE-FTS and lidar [e.g., Manney et al, ACP, 2008], and HALOE and UARS MLS
- Comparisons with this climatology will help characterize deficiencies in the representation of the stratopause in current operational analyses
- Recent high-quality satellite data are being used to help improve representation of the stratopause in models and data assimilation systems

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